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September 1980

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ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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This document contains copies of the addresses presented during the opening session of the Army Symposium on Solid Mechanics, 1980. This meeting was held at Bass River (Cape Cod), Massachusetts during September 30-October 2, 1980 and was conducted on the theme "Designing for Extremes: Environment, Loading, and Structural Behavior".

JOB

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PREFACE

This is the seventh in our series of biennial symposia held under the aegis of the U. S. Army Materiel Development and Readiness Command (DARCOM) through its Materials Advisory Group (MAG) and more specifically the Mechanics of Materials Technical Working Group (TWG).

The Mechanics of Materials TWG is directed by AMMRC and consists of members from all of DARCOM's R&D Commands. The Solid Mechanics Symposium Committee is comprised of Mechanics of Materials TWG membership, augmented by representatives of the U.S. Army Corps of Engineers, the U. S. Air Force, U.S. Navy, the National Bureau of Standards, and NASA-Lewis Research Center. Such broad participation, which began with the 1974 meeting results from the fact that solid mechanics is a vital element in development of advanced systems.

The Mechanics of Materials TWG was established in 1964, to assist in formulating the Army wide program in solid mechanics and in promoting scientific and technical exchange among DoD laboratories. This TWG is composed predominately of bench level technical experts in the specific areas of materials and mechanics. Perhaps the most important function of the Mechanics of Materials TWG is the exchange of technical information and the sponsorship of these biennial Solid Mechanics Symposia.

This document contains copies of the addresses presented within the opening session at the Army Symposium on Solid Mechanics, 1980. This meeting was conducted on the theme "Designing for Extremes: Environment, Loading, and Structural Behavior" and was held at Bass River (Cape Cod), Massachusetts during September 30 - October 2, 1980. The proceedings of this conference are published in a companion document, AMMRC MS 80-4 dated September 1980. There is also another companion document, AMMRC MS 80-5, dated September 1980, which contains extended abstracts of the presentations made within the Work-in-Progress Sessions of the symposium. These sessions were comprised of a series of brief presentations and discussions of current (but not necessarily complete) research relating to the theme of the meeting.

We greatfully acknowledge Max Williams, Dean of Engineering, University of Pittsburgh, who delivered the very interesting and relevant keynote address on "Coping with Extremes for Structural Performance." Our gratitude also goes to the clerical staff of the Mechanics and Engineering Laboratory and the Technical Reports Office of the Army Materials and Mechanics Research Center for their unflagging efforts in the preparation and printing of numerous symposium materials.

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* These documents may be ordered from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

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ARMY SYMPOSIUM ON SOLID MECHANICS, 1980

DESIGNING FOR EXTREMES:

ENVIRONMENT, LOADING, AND STRUCTURAL BEHAVIOR

I. WELCOME AND INTRODUCTION

GEORGE W. SIBERT
Colonel, Infantry
Deputy Director/Commander
Army Materials and Mechanics Research Center

II. OPENING REMARKS - DESIGNING FOR EXTREMES

EDWARD M. LENOE
Symposium Chairman
Chief, Mechanics of Materials Division
Army Materials and Mechanics Research Center

III. KEYNOTE ADDRESS

COPING WITH EXTREMES FOR STRUCTURAL PERFORMANCE

M. WILLIAMS
Dean of Engineering
University of Pittsburgh

South Yarmouth, Cape Cod, Massachusetts

September 30-October 2, 1980

WELCOME AND INTRODUCTION

GEORGE W. SIBERT
Colonel, Infantry
Deputy Director/Commander
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

It is my pleasure to initiate this year's Army Symposium on Solid Mechanics and to welcome you here today. In addition to greeting you, the Symposium Committee has asked that I make a few introductory remarks. Since some of you are newcomers to this Symposium series, as am I, it seems appropriate to describe briefly some of the Army Materials and Mechanics Research Center (AMMRC) activities and capabilities. I will also highlight recent areas of emphasis at the Center. While AMMRC may be new to some of you, it is interesting to reflect that AMMRC is not new to United States defense activities. AMMRC is proud, not only of its present achievements, but also of its history, traceable to the era of Andrew Jackson's Presidency. For over 164 years, AMMRC and its predecessor agencies at the Watertown Arsenal have made important contributions to the U. S. Army.

AMMRC DESCRIPTION

For many years now, AMMRC has functioned as an independent multi-mission research center of the Army Materiel Development and Readiness Command (DARCOM) and served as a focal point for materials research and development. The Center is chartered by DARCOM to be the Lead Laboratory for Materials Technology, Solid Mechanics Technology and Materials Testing Technology. As a consequence of these responsibilities, AMMRC plans and executes studies at the forefront of each of the technologies. (Figures 1-3)

A fundamental requirement to complete our mission successfully is the resident inhouse expertise and facilities. These allow conduct of R&D in metals, ceramics, polymers and composites. Also needed to meet our objectives are intensive activities in the fields of applied mechanics, testing, specifications and standards, materials processing and manufacturing technology.

Our three laboratories are located on a 48 acre site along the Charles River in Watertown, about 6 miles west of Boston. There are ten major buildings containing 435,000 square feet. The Center supports approximately 690 personnel and about 262 of these are scientists, engineers and technicians. AMMRC also manages an extensive contract activity, in addition to the in-house studies. (Figures 4-7)

Besides the continuing long term research efforts, AMMRC is responsive to the day-to-day needs of the entire Army Materiel Development and Readiness Command. We refer to this as user assistance where the "user" may be a Program/Project Manager, one of the R&D Commands or Readiness Commands. We also interact with the Army "user", TRADCOC and its schools and centers.

Thus the range of assistance varies from thorough, in-depth studies, all the way to immediate assistance. The extent of effort depends upon assistance required and includes same-day transfer of technical information, to in-depth, on site evaluation and corrections for systems problems. Through such actions definition of pacing problem areas and new ideas are developed to provide insight for future studies at AMMRC.

SOME GENERAL OBJECTIVES

The primary resource for AMMRC for attaining its major objectives is its technology base program, consisting of so-called 6.1, 6.2 and 6.3A funded projects (basic and applied research and prototype demonstrator studies). Typically, in any given year, we carry on more than 120 Work Units and related contractor efforts.

Insight into some of the short term AMMRC objectives for various Army Materiel can be gained by referring to the illustrations for Aircraft, Armament, Armor, Missiles, Ground Vehicles and Multi-Mission/Special Requirements (Figures 8 through 13). Even a brief consideration of these short term objectives leads one to appreciate the utmost necessity of full understanding of the Techniques of Designing for Extremes. Obviously, without such methodology, advanced materials cannot be rationally introduced into our arsenal of weapons. For this reason, I am especially happy to welcome you to this Symposium and now look forward to a productive meeting in these next few days.

AMMRC

LEAD LABORATORY FOR

- **MATERIALS TECHNOLOGY**
- **SOLID MECHANICS TECHNOLOGY**
- **MATERIALS TESTING TECHNOLOGY**

FIGURE 1 - DARCOM CHARTERS

- TO BE THE FOCAL POINT FOR MATERIALS DEVELOPMENT WITHIN THE ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND
- TO PERFORM MATERIALS RESEARCH AND DEVELOPMENT AT THE FOREFRONT OF TECHNOLOGY
- INSURE RESPONSIVENESS TO USER REQUIREMENTS

FIGURE 2 - AMMRC'S FUNCTION

- MANUFACTURING TECHNOLOGY MANAGEMENT SUPPORT
- CONDUCT DARCOM INDUSTRIAL TRAINING PROGRAM
- EVALUATE PROPOSALS FOR ARO
- CONDUCT CONFERENCES AND SYMPOSIA
- MANAGE INFORMATION ANALYSIS CENTERS

FIGURE 3 - OTHER AMMRC FUNCTIONS

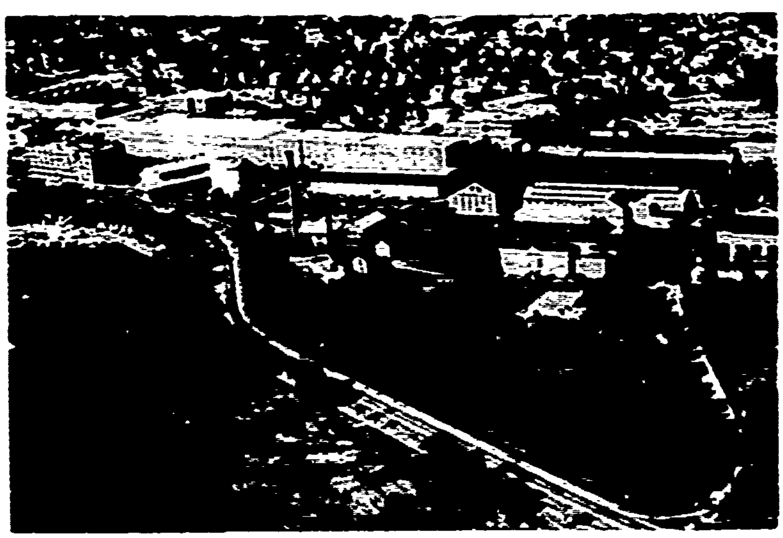

FIGURE 4 - FACILITIES

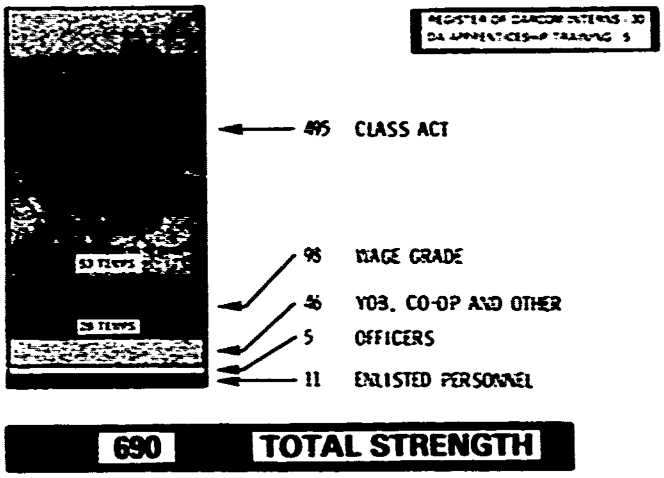

FIGURE 5 - MANPOWER STATISTICS FY80

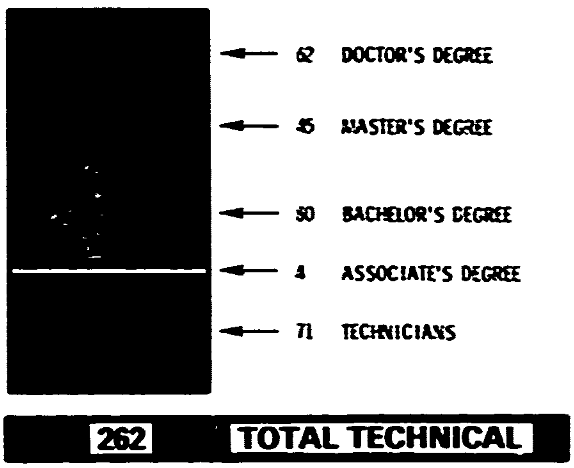

FIGURE 6 - TECHNICAL PERSONNEL FY80

- 48 ACRES
- 10 MAJOR BUILDINGS
- 632,000 TOTAL SQUARE FEET IN USE
- 389,000 SQUARE FEET LABORATORY SPACE
- 674 TOTAL PERSONNEL
- 262 TECHNICAL PERSONNEL
- 65 OTHER DARCOM PERSONNEL SUPPORTED
- $37,037,000 TOTAL FY79 FUNDING

FIGURE 7 - AMMRC STATISTICS

AIRCRAFT ENGINES	• INCREASE ENGINE EFFICIENCY VIA HIGHER GAS INLET TEMPERATURES ATTAINABLE USING NEW ALLOYS, COATINGS, COMPOSITES, AND CERAMICS
	• LENGTHEN LIFE BY IMPROVED FRACTURE TOUGHNESS, STRESS RUPTURE, AND FATIGUE BEHAVIOR
HELICOPTER DRIVE SYSTEMS	• SELECTIVELY STIFFEN TRANSMISSION CASE USING METAL MATRIX COMPOSITES - REDUCE LIFE CYCLE COSTS 42%
	• DEVELOP IMPROVED GEAR MATERIALS FOR 450°F SERVICE
SKINS/STRUCTURES/COMPONENTS	• DEVELOP IMPROVED COMPOSITE STRUCTURES AND MATERIALS
	• VERIFY DESIGN AND ANALYSIS PROCEDURES
	• PREDICT AND PREVENT ENVIRONMENTAL DETERIORATION

FIGURE 8 - SHORT TERM OBJECTIVES - ADVANCED MATERIALS FOR AIRCRAFT

ADVANCED ARMAMENT CONCEPTS	• NEW MATERIALS FOR ROTATING BANDS, SEALS, OBTURATOR PADS, WATER VAPOR BARRIERS, AND CANNON TUBES
	• HIGH DENSITY PENETRATORS
	• IMPROVED FRAGMENTATION MUNITIONS
MATERIALS ADVANCES	• INCREASED WEAR LIFE
	• IMPROVED CORROSION RESISTANCE

FIGURE 9 - SHORT TERM OBJECTIVES - ADVANCED MATERIALS FOR ARMAMENT

AIRCRAFT	• ENHANCED PROTECTION AGAINST SMALL ARMS, MISSILE AND SHELL FRAGMENTS
GROUND SYSTEMS	• IMPROVED PROTECTION AGAINST SMALL ARMS, FRAGMENTS FROM ARTILLERY, GRENADES, AND MINES
CREW BALLISTIC PROTECTION	• FURTHER DEVELOP SPALL PROTECTIVE LINERS FOR COMBAT VEHICLES. IMPROVED ARMOR FOR CRASHWORTHY HELICOPTER CREW SEATS
SPECIAL REQUIREMENTS	• ARMOR DEVELOPMENT FOR EXECUTIVE DEPARTMENT
	• ACQUISITION AND DISSEMINATION OF BALLISTIC DATA FOR MATERIALS FOR DoD

FIGURE 10 - SHORT TERM OBJECTIVES - ADVANCED MATERIALS FOR ARMOR

MISSILE GUIDANCE	• DEVELOP HYPERSONIC RADOME MATERIALS WITH MACH 5^{+} RAIN EROSION CAPABILITIES
SKINS/STRUCTURES	• DEVELOP IMPROVED COMPOSITES
	• CONTROL STRESS CORROSION CRACKING AND FRACTURE
	• DEVELOP IMPROVED WELD REPAIR PROCEDURES

FIGURE 11 - SHORT TERM OBJECTIVES - ADVANCED MATERIALS FOR MISSILES

HEAT ENGINES	• INTRODUCE CERAMICS INTO ADIABATIC TURBO COMPOUNDED DIESEL - 33% IMPROVED IN FUEL CONSUMPTION
REDUCED WEIGHT VEHICLES	• PROCESS OPTIMIZATION OF COMPOSITE BODY COMPONENTS
IMPROVED COMPONENTS	• HARDEN VEHICLE HULL, TRACK COMPONENTS AND SUSPENSION SYSTEMS AGAINST BLAST
	• IMPROVE FATIGUE CAPABILITIES AS WELL AS MULTI HIT RESISTANCE

FIGURE 12 - SHORT TERM OBJECTIVES - ADVANCED MATERIALS FOR GROUND VEHICLES

FIRE RESISTANT MATERIAL	• CHARACTERIZE PYROLYSIS AND FLAMMABILITY BEHAVIOR, DEVELOP IMPROVED PLASTICS
LASER HARDENING	• PROVIDE MATERIALS AND STRUCTURES TECHNOLOGY BASE TO MEET HIGH ENERGY LASER THREAT
DAMAGE TOLERANT/FAIL SAFE SYSTEMS	• INCREASE OPERATIONAL LIFE OF WEAPON SYSTEMS
BRIDGING	• EXPLOIT COMPOSITE MATERIALS FOR ADVANCED, HIGH PERFORMANCE BRIDGING
NONDESTRUCTIVE TESTING	• DEVELOP NEW AND ADVANCED NDT, MAINTAIN TRAINING SCHOOL

FIGURE 13 - SHORT TERM OBJECTIVES - MULTI-MISSION/SPECIAL REQUIREMENTS

OPENING REMARKS - DESIGNING FOR EXTREMES

Edward Mark Lenoe
Symposium Chairman
Army Materials and Mechanics Research Center
Watertown, Massachusetts

Very soon we will be immersed in highly specialized discussions of the technical aspects of Designing for Extremes. However, before beginning the meeting, it is appropriate to extend our thanks to all who contributed to the planning and execution of this enterprise. Therefore, it is with a sense of pleasure that I express my gratitude to the Program Committee for their achievement in organizing this Solid Mechanics Symposium. Now rather than bore you with platitudes concerning the importance and success of this continuing series of Symposia, I choose instead to share with you some ideas and recent readings which I found stimulating (1 thru 4). No doubt, prior to dealing with narrow specialties, it is also opportune to consider the broader aspects of our engineering endeavors.

The Tragic Need for Mechanical Technology R&D

During the last decade, in the international arena, the technological position of our nation has eroded substantially and our economy in particular has worsened at an increasing rate for the past few years. Review of economic indicators dealing with the manufacture of consumer goods, suggests that long term deterioration has been underway [1] and that the United States suffers a major technological trade deficit estimated to cost a minimum of $10 billion/yr. This deficit is anticipated to worsen in the next 3 years to reach a probable $40 billion annual deficit in our trade in manufactured goods associated with mechanical technology. Needless to say, such increasing losses, combined with trade loss due to importing oil, coffee and other non-manufactured goods, are primary causes for the weakening U.S. dollar. Many aspects of our technology have long been ignored, not only by government agencies, but by industry as well. If our nation is to remain competitive in international markets, mechanical technology can no longer be ignored.

What is the relationship between lack of funding of R&D in mechanical technology and loss of trade in U.S. Manufactures? Tesar [1] has shown that the major portions (75%) of U.S. manufactures trade is governed by mechanical technology. There is an increasing perception that energy is a significant problem for our economy. In this context, it is useful to contrast energy sufficiency and trade balance for the leading technologically based nations. Figure 1 clearly shows U.S. trade deficits contrasted to substantial surpluses of the Japanese and German economies. Considering their limited energy resources and trade surpluses, leads one to conclude that a major U.S. problem is the efficient conversion of energy and natural resources into consumer goods. Now consider the very basis of productivity. E. F. Denison, of Brookings Institute, estimates that 38% of our productivity increase over the past four decades has been due to technology. Figure 2 documents other contributing factors: capital, labor

quality, economies of scale and resource allocation. Further, regarding productivity, U.S. Bureau of Labor Statistics show that the annual productivity increase of the U.S. Worker in the 13-year period 1960-73 was 3.4%, which is lower than all other major Western trading nations. Figure 3 reveals that productivity increases in these nations outstripped ours by anywhere from about 17% in Canada to about 200% in Japan. More recent data also show the U.S. as continually lagging. Inadequate capitalization is part of the cause of this diminishing productivity. The average investment per worker decreased from $258 in 1967 to $220 per worker in 1973. In West Germany, corresponding values were $298 to $693 and in Japan $191 to $324 for the same time period. Comparative investments are further shown in Figures 4 and 5.

Regarding trade deficits, Figure 6 identifies the major trade categories for 1978. Notice that the total trade in manufactures is greater than non-manufactures. Further, note the breakdown of the manufactures trade into three categories: mechanical, chemical and electrical. Figure 7 shows the categories in mechanical systems, which represented 75% of our trade in 1978. Aircraft and spacecraft reflect positive trade balance, but the Japanese and European consortiums are striving mightily to make in roads in this sector. Also shown in the same graph is the importance of heavy and light machinery. The U.S. has always prided itself on leadership in heavy equipment. However, recently we have taken to providing turn-key manufacturing facilities to military as well as commercial protagonists! While some support exists in materials and manufactures for heavy machinery, Federal support for light machinery is nonexistent. It is worth commenting that the combined trade loss from cars and trucks and light machinery was $21.5 billion in 1978, which amounted to 75% of our petroleum loss. There can be no doubt the federal and industrial support must be increased in mechanical technology related to these fields. Efforts must also be made to insure greater support of university research on the engineering and technology for design and production of such products. Strong industry/university interaction must be developed. Furthermore, an appropriate climate for capital investment must be fostered to encourage investments in plants, equipment and tools that exploit new technology.

Perhaps this commentary, put forth by an employee of DOD, advocating investment in commercial matters, strikes one as inappropriate. However, as will be demonstrated shortly, the Federal government plays the leading role in sponsoring research, obviously this research should be directed towards national interests. Furthermore, it is rather easy to prove that severe deficiencies in manufacturing technologies do have a profound negative impact on numerous military materiel.

Current R&D Resources for Technology

In 1979, the federal government and industry supported a total R&D program of about $52 billion, with the government supporting 49.3% of the activity and industry performing 71%. For that year, the government performed 13%, universities 10% and other nonprofit institutes performed about

5.6% of the R&D program. Figure 8 shows various agency budgets, while Figure 9 compares differenc engineering research categories. Materials is clearly the major emphasis of basic engineering research, at 38.8% of the total. Out of the total federal budget, basic engineering research is 8.9% of the effort and Mechanical Engineering is only 0.6% of the funds. Basic research is dominated by four agencies, with DOD, NSF, DOE and NASA accounting for 95.5% of the budget. Figure 10 illustrates that DOE and DOD in particular place a heavier emphasis on mechanical engineering than the other federal agencies. From this discussion, one must conclude that there is a deficiency in funding related to mechanical technology. While DoD maintains a far more balanced input into such effort, on the national level, in other Federal agencies, there is a necessity to increase such funding to protect the economic status of our country. There is no doubt that general lack of support impedes the technological innovation process, a matter of vital concern not only in consumer products, but obviously of importance in the development of weapons systems. In this area, not only lack of funds but the educational process itself must bear the burden of fault. Industrial employers often complain that recently graduated engineers tend to lack the practical knowledge necessary to achieve technical change at the production level. Our engineering cirriculum has been criticized for emphasizing techniques, rather than creativity and boldness. Thus far the main complaint voiced here has been that of misdirected appropriations. However, it is useful to consider other aspects of the technology of introducing new materials and developing alternate systems concepts.

UNATTAINED GOALS AND ESCALATING COSTS

We are all familiar with cost overruns often associated with advanced systems development. Such problems are typified in the special to Boston Globe, July 6, 1980, by John Bierman, Headed for the Scrap Heap? Bierman reported that despite the fact that $3 billion had already been spent on development of the new U.S. Navy-Marine Corps fighter, the F/A18 Hornet, some officials believe it may have to be scrapped because of performance problems and cost overruns. Rep. Bruce Vento (D. Minn.), one of the opponents of the Hornet, alleged that unit costs had soared from an estimated $6 million when the project was initiated five years ago to between $26 to $29 million today. Besides costover runs, he cited structural faults such as wing flexibility, collapsing landing gear, roll-rate problems, increased aircraft weight and recurrent bulkhead fatigue failure. There are, of course, numerous previous aircraft programs with similar cost and performance problems -- the F111 and the giant C5A transport. The C5A transport, for instance, has a critical wing fatigue life about 1/4th that of the other vital structural element capabilities. Apparently, in these days of increasing complexity and ever more demanding requirements, attaining a balanced system, such as exemplified by the legendary one-horse shay, is virtually impossible.

("Have you heard of the one-hoss shay
That was built in such a logical way
It ran a hundred years to a day? . . . .
End of the wonderful one-hoss shay.
Logic is logic. That's all I say")[2]

It is easy to find innumerable examples of cost overruns and unattained systems goals, not only in multi-million dollar hardware but in much lower cost items; guided artillery shells escalating an order of magnitude in costs from inception, anti-tank weapons with four-fold cost increments to mention a few.

However, we must be fair to the systems developers, since often project costs are forced to fit within available budgetary constraints. Quite typically a program manager will be forced to proceed with advanced engineering development while simultaneously confronted by increasing technical problems and decreasing fiscal resources. These as well as other circumstances tend to create a situation of unrealistic official cost estimates. Certainly, considering the infancy of many new systems and the fact that a good portion of associated cost estimating is therefore based on judgements made without prior experience, cost overruns are not surprising coinsequences.

One is tempted to place much blame on human frailties, such as ignorance, incompetence and greed. In this context, Florman[3], in his book attacking the anti-technologists, cites some suggestive data. For instance, a survey conducted by the National Science Foundation reported 50% of the scientific and engineering articles studied contained wrong data or did not have sufficient evidence to support the conclusions reached by the authors! Furthermore, Florman cites the fact that whereas 1,500,000 government employees classify themselves (via job descriptions) as engineers, application of conventional standards of education, training and capability would reduce this number by one third.[4] No doubt improvements are desirable in the quality of engineering and in society as well. However, the fact is that development of advanced systems is in its very nature a difficult process, fraught with difficulties, and burdened with many uncertainties, and requiring application of high level skills and judgement factors. Further development of such skills, as well as exploration of the limits of knowledge and uncertainties in the process of designing for extremes, are the very reasons for conducting this symposium. So without any further delay, I now introduce our eminent Keynote Speaker, Professor M. L. Williams, Dean of Engineering, University of Pittsburgh.

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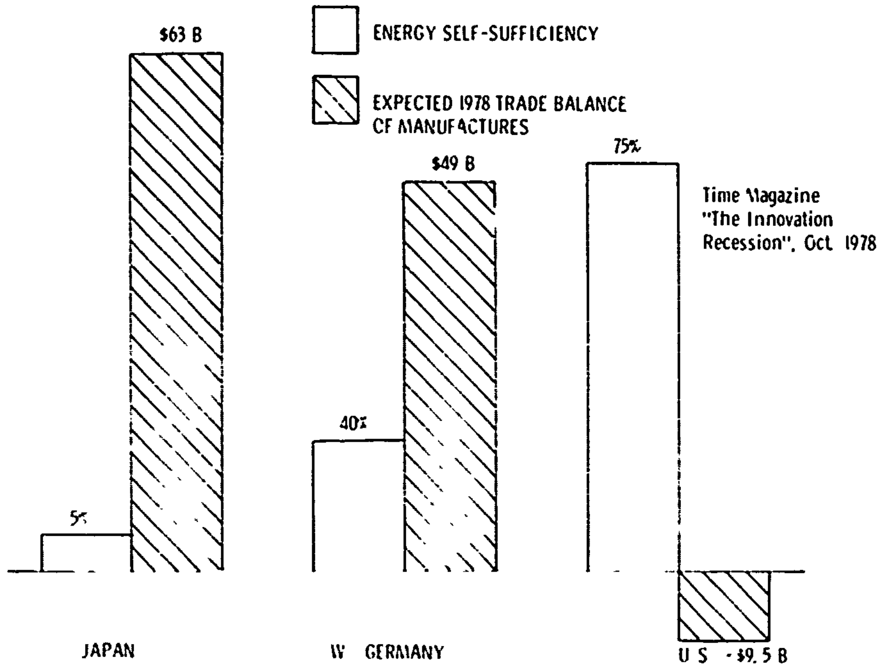

FIGURE 1 - 1978 EXPECTED TRADE BALANCE AND RELATED ENERGY SUFFICIENCY

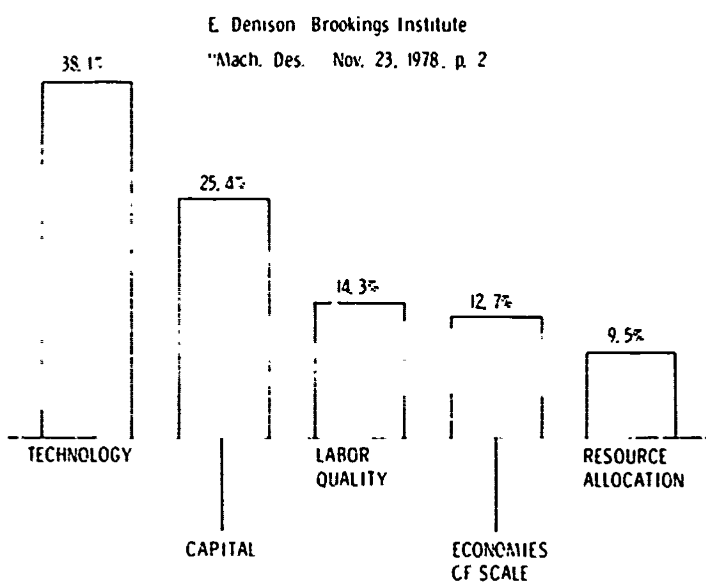

FIGURE 2 - CONTRIBUTION TO PRODUCTIVITY (1929 - 1969)

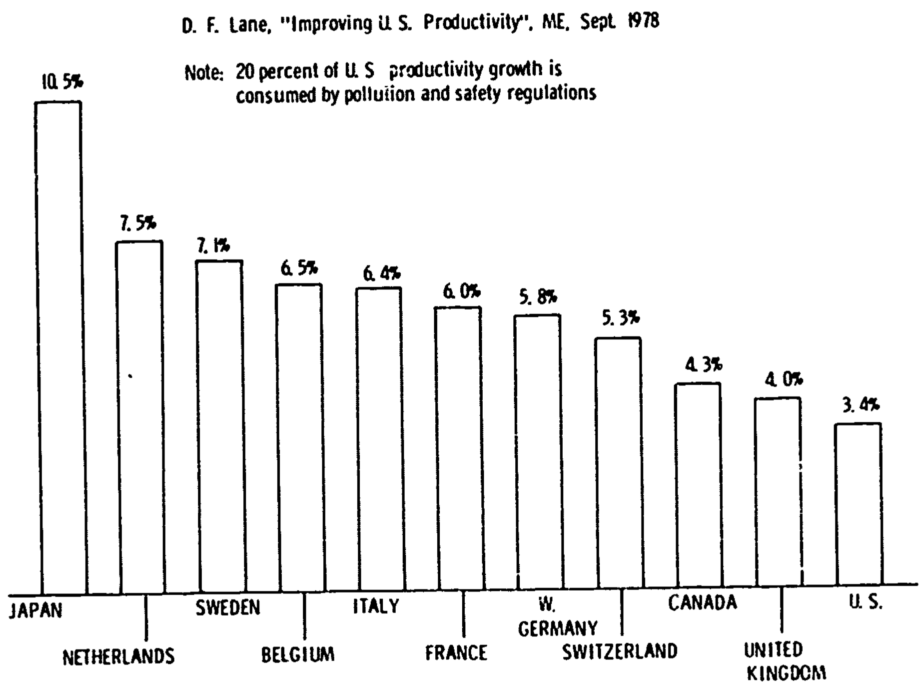

FIGURE 3 - ANNUAL WORKER PRODUCTIVITY INCREASE IN MANUFACTURING

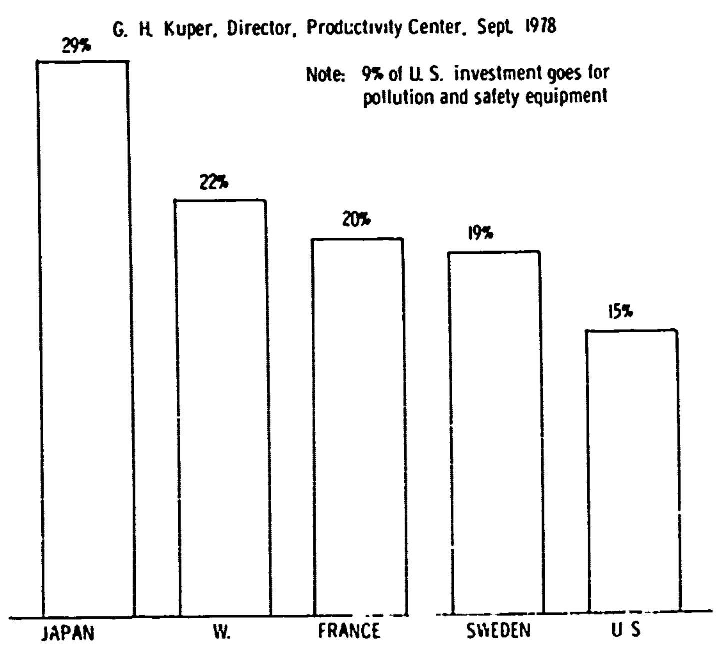

FIGURE 4 - PERCENTAGE OF GROSS DOMESTIC PRODUCTS INVESTED ANNUALLY IN PLANTS AND EQUIPMENT (1960 - 1975)

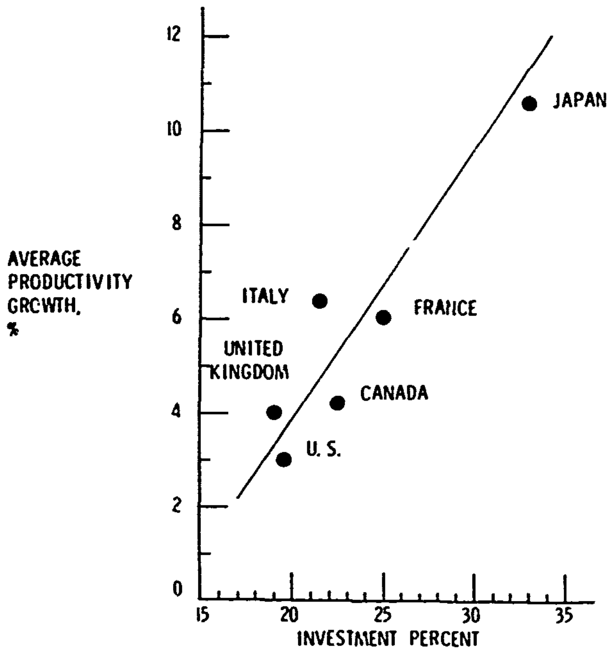

FIGURE 5 - CORRELATION BETWEEN PRODUCTIVITY GROWTH AND INDUSTRIAL CAPITAL INVESTMENT (1960 - 1973)

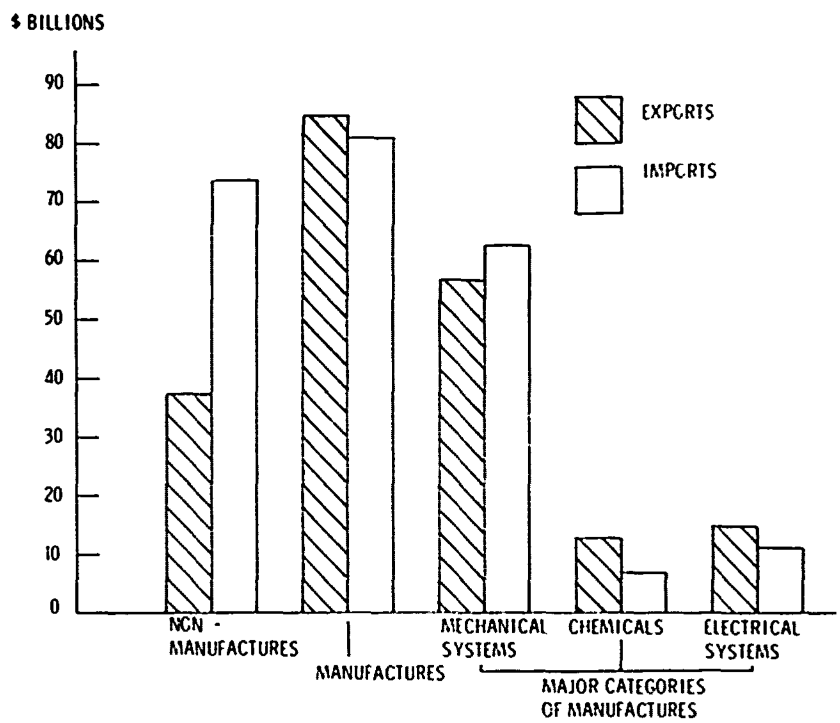

FIGURE 6 - 1978 IMPORTS AND EXPORTS OF MAJOR TRADE CATEGORIES

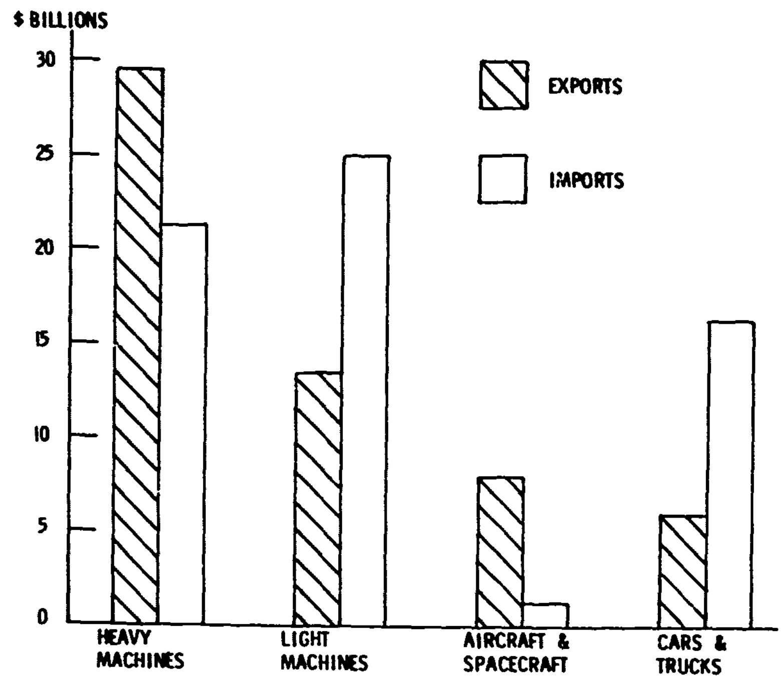

FIGURE 7 - 1978 IMPORTS AND EXPORTS - MECHANICAL SYSTEMS

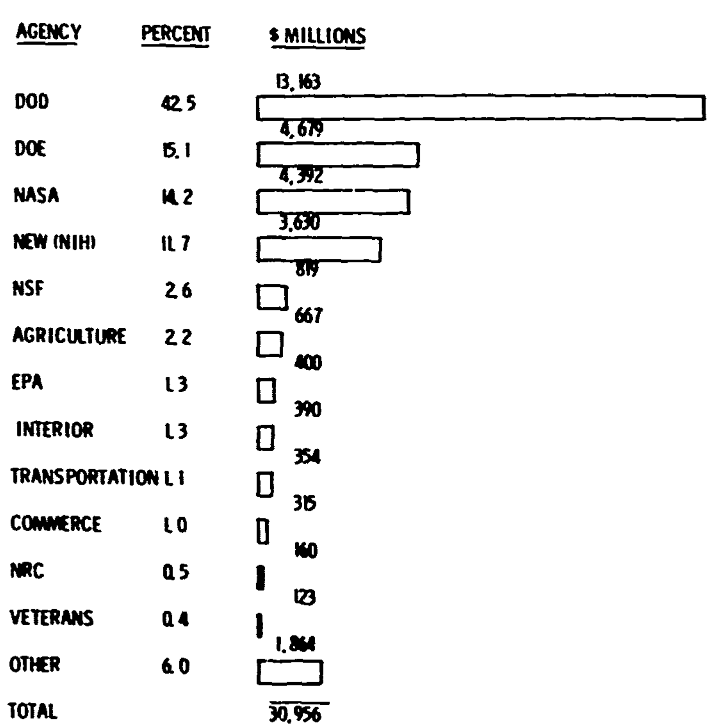

FIGURE 8 - THE 1979 ESTIMATED R&D BUDGET ITEMIZED BY AGENCY

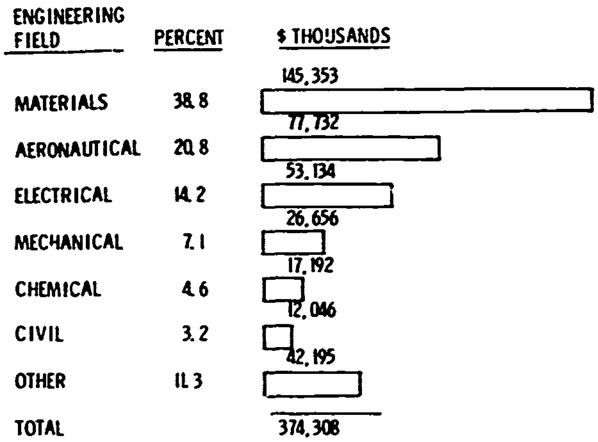

FIGURE 9 - FEDERAL FUNDS ALLOTTED FOR BASIC ENGINEERING TO USDA, DOC, DOD, DOE, NASA and NSF FY 79

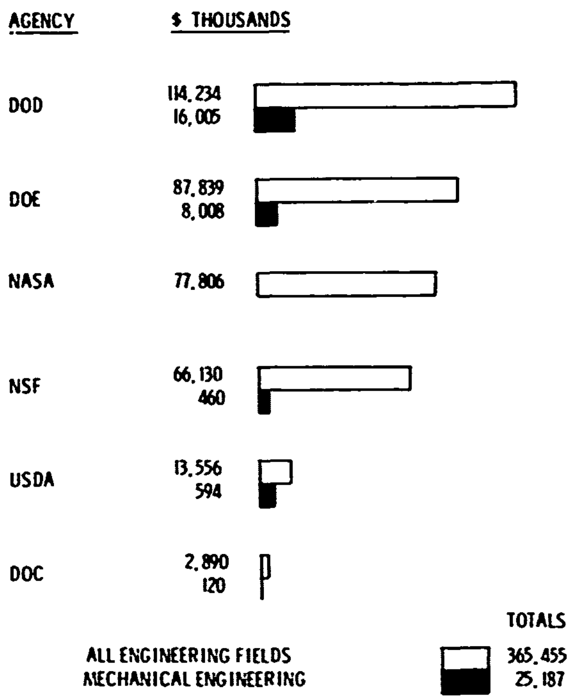

FIGURE 10 - FEDERAL FUNDS FOR BASIC RESEARCH IN ENGINEERING ITEMIZED BY AGENCY IN THE FY 1979 ESTIMATED BUDGET

KEYNOTE ADDRESS

COPING WITH EXTREMES FOR STRUCTURAL PERFORMANCE

M. L. WILLIAMS
Dean of Engineering
University of Pittsburgh
Pittsburgh, Pennsylvania 15261

SUMMARY

Aside from the important mainstream activities in structural mechanics which must never be neglected, extensive attention must be paid to expanding the existing perimeters of our field. Research and the applications of technology at this "cutting-edge" have been consistently responsible for the many facets of the technological advantage this country needs on a continuing basis in order to maintain both commercial and military supremacy. In the present technological and economic climate, the United States has been forced to choose its primary technical targets more selectively while simultaneously taking steps to maintain the integrity of our baseline efforts. Two basic elements must be pursued: (1) creative selectivity in choosing our primary technical areas, and (2) quality performance in the follow through.

Within the context of this meeting, it is important to recognize that the subject of structural mechanics as a major part of the design cycle has at least two main subsidiary components, namely fundamental studies of mechanical behavior of solids (usually as candidate components in a design) and the successful performance to specifications of the synthesized assembly of such components.

For structures, the innovator is usually the designer; in solid mechanics the innovator is frequently the materials engineer-scientist. The structural mechanics analyst supports both aspects with his own innovation - normally directed toward immaginative ways to treat the phenomena imposed at the extremes of the performance envelope of the design. Parenthetically, the major contribution of numerical computational methods made possible by the significant advances in computer science and engineering must be recognized. Simultaneously, however, there is an elementary caution to be observed. The tendency to "over-compute" just because the capability exists must continually be dampened.

Having established the position that there are two major components of structural mechanics, consider the maintenance of our minimum baseline technical capability, and then a consideration of the impact which various extreme conditions in the loading environment have upon the behavior of the materials and of the design.

In order to maintain a broad baseline technical competence in the face of increased cost, which thus suggests more focussed thrusts, greater use can be made of technology transfer. The basic idea is to utilize and adapt the work of others, in a monitoring mode, to your own ends. The decreased cost associated with not conducting that work yourself is of course accompanied by an associated penalty for currency. The advantage is the increased time for developing selected target areas. While this idea is not new, perhaps its current timeliness is. The transfer commonly takes place through the technical media and appears to be most effective when conducted upon a person-to-person basis. For the United States, the most promising returns are probably through increased use of foreign sources, although the absence of our foreign language facility must be rectified in order to obtain the best result.

When appropriate protection of our baseline technology has been attained, an increasing emphasis can be devoted to selected areas of investigation, which are characteristically found at the boundaries of our present experience.

From the point of view of the mechanics of solids, one of the easiest approaches is to consider changes which are reflected in the equation of state or constituitive relation of the solid. When Robert Hooke in 1976 first expressed his anagram, ceiiinosssttuv, the state variables were essentially only pressure (stress) and volume (strain). To these we now commonly add temperature and time. Most of the "cutting edge" research advances occur at extremes of these four state variables. Simple examples include high static tectonic pressures, ultra high pressure technology, strain induced anisotropy, two modulus (K-bulk and G-shear) to one modulus (K-bulk) transition with change of temperature, and time (strain rate) effects in explosive forming. More sophisticated examples, frequently bordering upon materials science, include changes in surface and interfacial chemistry, metal phase changes, and the strong polymeric time-temperature sensitivity as the state variables vary over increasingly wide ranges.

Instead of concentrating upon the pointwise constitutive relations governing the behavior of a (continuous) solid at a point, the overall structural design tends to be environmentally sensitive -- in the broadest sense. Here, the influences of extremes upon the structural assemble, or even the pointwise state variables, occur from imposed conditions such as body and surface forces causing a phenomenological change in the structure such as instability, excessive deformation, or adhesive or cohesive material separation. Simple examples include Euler-type buckling with or without temperature or side pressure, mechanical and chemical corrosion and erosion such as occurs in cavitation damage to marine propulsion or gas turbine deterioration in hostile environments, nose cone erosion, radiation, contamination of materials, acoustic fatigue in jet engines, debonding of composite materials, or fracture under kinetic penetration.

Other requirements also drive design. The importance of weight reduction in aeronautics was recognized very early by the Wright Brothers and was demonstrated recently by Paul MacCready in the Gossamer designs. Even present automotive design is being drastically overhauled in the drive for weight reduction due to the close coupling between vehicle weight and fuel consumption. The same minimum weight consideration occurs in military operations, not only for improved fuel economy in tanks and other vehicles, but also in the desire to obtain very light weight and very portable bridging for tactical operations. Here, as in most of the weight reduction programs, the limitation to minimum weight is buckling instability

The question of design with composite materials is a particularly interesting one. From the morphological standpoint considering, say, three generic materials, i.e. metals, polymers, and ceramics, one may easily generate 19 different combinations. Are the various material combinations continua or structures? While it obviously depends upon the relative dimensional scales involved, most of the combinations tend to resist easy characterization. From a distance, any of them appear to be continua, but upon close inspection, e.g. at fracture origins, each is a structure whose localized or pointwise behavior has not been well explained.

In the verbal presentation, selected illustrations will be presented to show cases of special interest wherein various extreme conditions affect the behavior of the component or the assembled design.